

# The $[\alpha/\text{Fe}]$ Ratios in Dwarf Galaxies: Evidence for a Non-universal Stellar Initial Mass Function?

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**Abstract** It is well established that the  $[\alpha/\text{Fe}]$  ratios in elliptical galaxies increase with galaxy mass. This relation holds also for early-type dwarf galaxies, although it seems to steepen at low masses. The  $[\alpha/\text{Fe}]$  vs. mass relation can be explained assuming that smaller galaxies form over longer timescales (downsizing), allowing a larger amount of Fe (mostly produced by long-living Type Ia Supernovae) to be released and incorporated into newly forming stars. Another way to obtain the same result is by using a flatter initial mass function (IMF) in large galaxies, increasing in this way the number of Type II Supernovae and therefore the production rate of  $\alpha$ -elements. The integrated galactic initial mass function (IGIMF) theory predicts that the higher the star formation rate, the flatter the IMF. We have checked, by means of semi-analytical calculations, that the IGIMF theory, combined with the downsizing effect (i.e. the shorter duration of the star formation in larger galaxies), well reproduces the observed  $[\alpha/\text{Fe}]$  vs. mass relation. In particular, we show a steepening of this relation in dwarf galaxies, in accordance with the available observations.

## 1 Introduction

The integrated galactic initial mass function (IGIMF) theory [6] is based on the following 3 assumptions:

- most stars in galaxies form in star clusters (SCs). Within each SC, the IMF can be approximated by  $\xi(m) \propto m^{-\alpha}$ , with  $\alpha = 1.3$  for  $m < 0.5 M_{\odot}$  and  $\alpha = 2.35$

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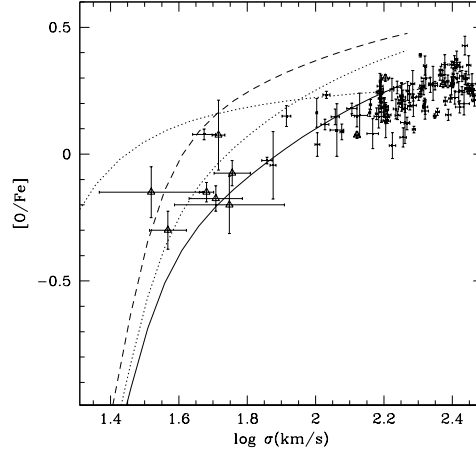
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**Fig. 1** [O/Fe] vs.  $\sigma$  for models with a constant SFR over a period of time  $\Delta t$  (see text). Different values of  $\beta$  (slope of the SC mass distribution function) are considered: 2.35 (heavy solid line), 2 (heavy dotted line) and 1 (heavy dashed line). Also plotted is a model with  $\beta = 2$  and  $\Delta t = 1$  Gyr, irrespective of the galaxy mass (light dotted line). Observational data are from [5] (filled squares) and from [4] (open triangles).

for  $0.5 M_{\odot} < m < m_{\max}$ . The value of  $m_{\max}$  depends on the mass of the SC (the larger the mass, the higher the probability of forming massive stars).

- Also the SCs are distributed according to a power law,  $\xi_{\text{ecl}} \propto M_{\text{ecl}}^{-\beta}$ , where  $M_{\text{ecl}}$  is the mass of the SC. Observations suggest  $\beta$  to be about 2 [1].
- The maximum possible mass of a SC increases with the star formation rate (SFR) of the galaxy [2]. The IGIMF in galaxies depends thus on the SFR. Galaxies with high SFRs contain larger clusters and, consequently, a larger fraction of massive stars. The IMF is therefore flatter than in galaxies with low SFRs.

## 2 Aims and assumptions

We study how the  $[\alpha/\text{Fe}]$  ratios in galaxies are affected by the steepening of the IGIMF with decreasing SFR. Our aim is to reproduce the correlation between  $[\alpha/\text{Fe}]$  and mass (or velocity dispersion  $\sigma$ ) observed in early-type galaxies. We assume for simplicity the SFR to be constant over a period of time  $\Delta t$ , which increases with decreasing galaxy mass, in compliance with downsizing ([5]; see Fig. 2, right panel, dashed line). The Type Ia (main producers of Fe) and Type II (main producers of  $\alpha$ -elements) Supernova rates can be thus calculated analytically, within the IGIMF framework.

### 3 Results and conclusions

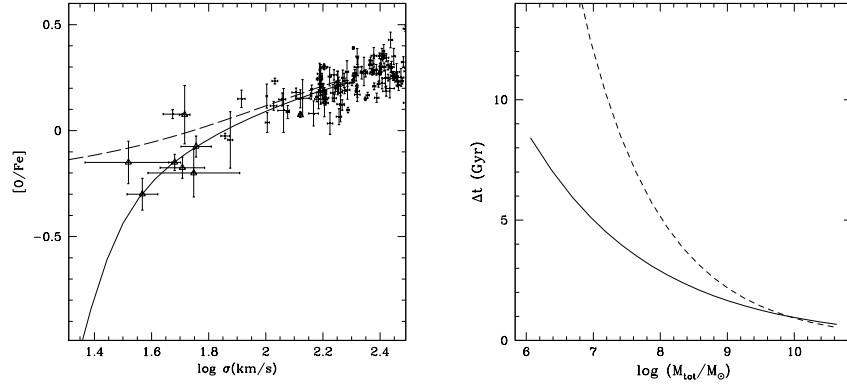
We calculate both mass-averaged and luminosity-averaged [ $\alpha$ /Fe] ratios in early-type galaxies of different masses (which we convert to  $\sigma$  through the Faber-Jackson relation). In Fig. 1 we compare the resulting [O/Fe] (without fine tuning of the parameters) as a function of the slope of the SC mass distribution function  $\beta$  (heavy lines) with the available observations. The evolution of [Mg/Fe] is very similar to the [O/Fe] evolution and we do not report it here. We reproduce qualitatively the increase of [ $\alpha$ /Fe] with  $\sigma$ . This result is partially due to the downsizing (in low-mass galaxies the SFR lasts longer and the SNeIa have more time to pollute the galaxy). To demonstrate that, we plot a model with  $\beta = 2$  and with constant  $\Delta t = 1$  Gyr, irrespective of the galaxy mass (light dotted line). This model turns out to be too flat and does not reproduce well the data, therefore the downsizing is a necessary ingredient to reproduce the [ $\alpha$ /Fe] vs.  $\sigma$  relation.

However, because of the steeper IMF in dwarf galaxies (resulting in a lower SNI rate), our theoretical curves bend down at low  $\sigma$ . This result is in agreement with the available observations.

In order to best fit the available data, we allow a variation in the SNIa parameters and, most importantly, in the  $\Delta t$ -luminous mass relation. Our best fit is shown in Fig. 2, left panel (solid line) and is based on the relation shown in Fig. 2, right panel (solid line). From this plot we can notice that the downsizing effect (namely the shorter duration of the star formation in larger galaxies) is milder than in [5], in the sense that the  $\Delta t$  for large galaxies is slightly larger than the timescale calculated by [5]. Also shown in Fig. 2, left panel is the best fit [ $\alpha$ /Fe] vs.  $\sigma$  obtained with a constant (i.e. not SFR-dependent) IMF (long-dashed line), obtained using the same modified  $\Delta t$ -luminous mass relation employed for the best fit IGIMF model. This curve reproduces well the data points at high  $\sigma$  but is less accurate at low  $\sigma$  because the [ $\alpha$ /Fe] does not steepen, as the available observations seem to indicate. It is also to note that the best fit has been obtained with  $\beta=2.35$ . More details about these calculations in [3]. It is clear that more observations of the [ $\alpha$ /Fe] ratios in dwarf galaxies are needed to test the validity of our results (see for instance the contribution of A. Rys in this volume).

The main conclusions of this work can be summarized as follows:

- Models in which the IGIMF theory is implemented naturally reproduce an increasing trend of [ $\alpha$ /Fe] with  $\sigma$ , as observed in early-type galaxies.
- These models show (at variance with constant IMF models) a steepening of the [ $\alpha$ /Fe] vs.  $\sigma$  relation for small galaxies, as the observations indicate.
- In order to best fit the observations, the downsizing effect (namely the shorter duration of the star formation in larger galaxies) has to be milder than previously thought.
- The best results are obtained for a star cluster mass function  $\xi_{\text{ecl}} \propto M_{\text{ecl}}^{-2.35}$ .



**Fig. 2** (Left panel)  $[O/Fe]$  vs.  $\sigma$  for our best fit IGIMF model (solid line) and for our best fit model with constant IMF (long-dashed line). (Right panel)  $\Delta t$  vs. luminous mass relation that has been employed in the best fit model in the left panel (solid line) and  $\Delta t$ –mass relation obtained by [5] (dashed line).

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